# General summary of the Home Energy Model core calculation

A technical explanation of the methodology

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Any enquiries regarding this publication should be sent to us at: homeenergymodel@energysecurity.gov.uk

# Contents

# Background to the Home Energy Model

## What is the Home Energy Model?

The Home Energy Model (HEM) is a calculation methodology designed to assess the energy performance of homes, which will replace the government's Standard Assessment Procedure (SAP).

The Home Energy Model is still under development and its first version will be implemented alongside the Future Homes Standard (FHS) in 2025. We are publishing information about the model while it is still at a formative stage to enable industry to participate in the ongoing development process.

## Where can I find more information?

- This document is part of a wider package of material relating to the Home Energy Model:

**Home Energy Model technical documentation (e.g. this document)**

**What:** This document is one of a suite of technical documents, which go into further detail on the methodology and the validation exercises that have been carried out. We intend to update and produce further technical documentation throughout the model development process.

**Audience:** The technical documentation will be of interest to those who want to understand the detail of how the Home Energy Model works and how different technologies are treated.

**The Home Energy Model consultation**

**What:** The Home Energy Model consultation, which explains the overhaul to the SAP methodology and seeks views on the approach taken by the new Home Energy Model.

**Audience:** The Home Energy Model consultation will be of interest to those who want to understand the proposed changes to the SAP methodology and wider SAP landscape.

**The Home Energy Model reference code**

**What:** The full Python source code for the Home Energy Model and the Home Energy Model: FHS assessment has been published as a Git repository. This code is identical to that sitting behind the consultation tool. We are currently considering whether the opensource code could serve as the approved methodology for regulatory uses of the Home Energy Model.

**Audience:** The reference code will be of interest to those who want to understand how the model has been implemented in code, and those wishing to fully clarify their understanding of the new methodology. It will also be of interest to any potential contributors to the Home Energy Model.

# Related content

This document provides a general summary of the overall structure of the Home Energy Model (HEM) core engine and the design principles underpinning it (with particular reference to how the calculation has been implemented in the code). For a general summary of the role and structure of wrappers, see HEM-TP-02 General summary of wrappers, and for wrappers for the FHS assessment see HEMFHS-TP-06 Summary of wrappers for the FHS assessment.

To understand how this methodology has been implemented in computer code, please see:

*src/core/project.py*

# Methodology

The Home Energy Model software is structured to facilitate the use of different sets of assumptions for different policy requirements. Fundamentally, this means that the software is divided into:

- A core calculation component which models heat transfer in the building, demand on heating, cooling and hot water systems and the resulting energy demand for electricity, mains gas etc.
- “Wrapper” components which add pre-processing (e.g., standardisation of occupancy assumptions) and post-processing (e.g., application of emissions and primary energy factors) steps to the core calculation which are suitable for different policies.

## 1. Design principles

The core calculation has been designed to be relatively unconstrained in the input specifications it accepts. For example, it does not put any limit on the number of zones as it is expected that any such limits required will be enforced in the relevant wrapper. The model is, however, currently limited to one heating system per zone. The model is also limited to a single water heating system (plus instantaneous electric showers) at the time of writing. Note that the space heating systems and the single water heating system can still have several components (e.g., hot water cylinder heated by multiple heat sources) and some components can provide more than one service (e.g., a heat pump providing both space heating and water heating).

The core calculation has a modular structure to maximise flexibility, to maximise the ability to add new technologies in the future and to maximise the ability to upgrade the treatment of technologies already covered. Each technology and component of a building system has its own module. The different modules are relatively self-contained and have few (or ideally, no) dependencies on the implementation details of other modules, which means that they can be connected together in many different ways relatively simply. For example, the boiler module can be connected directly to the water heating demand to model a combi boiler. or can be connected to the StorageTank module to model a regular or system boiler.

In the software, modules[1] are implemented using classes/objects[2] which can have internal properties/state and can communicate with each other. For example, if a hot water cylinder is present, then an instance of the StorageTank class will be created, with parameters including the volume of water stored and the standby loss rate. The StorageTank object will also have

[1] The term “module” can have multiple, subtly different meanings, depending on whether it refers to Python modules or conceptual modules in the Home Energy Model calculation. Therefore, the term will be avoided in favour of “class” or “object”.

[2] A class is a type of object, and an object is an instance of a class. There may be multiple objects of a given class, with different characteristics (where such characteristics are parameterised).

internal state in the form of the water temperature at different layers of the cylinder, which is invisible to other objects but which will affect the values (e.g. water heating demand) which the StorageTank object sends to other objects and will be affected by the values (e.g. hot water draw-offs and heat provided to the cylinder) received from other objects.

Each object will also have references to (i.e., will be connected to) other relevant objects. In the case of a StorageTank object, these will include those objects representing systems that provide heat to the cylinder (e.g., an ImmersionHeater object), which in turn may have references to other objects (e.g., an ImmersionHeater object may be connected to an OnOffTimeControl object). When an object has a reference to another object, it is able to call that object's public methods[3] in order to interact with it. This means that the control flow of the calculation will pass back and forth between several different objects during each timestep.

Together, a class's public methods constitute its interface. In order to maintain flexibility and extensibility of the software, classes that fulfil the same role should have the same interface, so that one can be substituted for another without requiring the objects using the interface to have any knowledge of what type of object is behind the interface[4]. Therefore, adding a new heating system to the model should usually[5] just be a case of implementing a new class which has an interface that is compatible with the interfaces of the existing heating system classes, rather than having to define relationships separately for every possible combination of objects.

# 2. Overall calculation structure

The calculation starts by initialising all the required objects based on the contents of the input data (either directly entered or from the relevant wrapper). It is at this stage that any internal variables and references between objects are initialised and any calculations that do not depend on the timestep are performed. Once all the objects have been initialised, the main calculation loop begins, and there will be one iteration of this loop run for each timestep in the calculation. As described above, data flows between objects are two-way in many cases and the control flow of the calculation goes in and out of different objects several times.

The main calculation loop can be divided into stages:

1. Calculation of hot water demand, water heating energy demand, delivered energy and fuel consumption by systems meeting this demand (including distribution losses and associated heat gains).

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[3] In addition to having variables that are only for internal use (known as private member variables), classes may also have functions that are only for internal use (known as private member functions or private methods) and functions that are for internal or external use (known as public member functions or public methods).
[4] In software development terms, the relevant concept is "polymorphism".
[5] For systems that have more complex interactions with other systems, it may sometimes be necessary to make further modifications to accommodate these additional interactions. This was the case with exhaust air heat pumps, for example, which also interact with mechanical ventilation in a way that the other heating systems implemented do not.

2. Calculation of space heating/cooling demand, delivered energy, fuel consumption by systems meeting this demand, and resulting internal air and fabric temperatures.
3. Additional calculations for any systems that provide multiple services (e.g., combi boiler providing both hot water and space heating).
4. Calculation of electricity generation, self-use and storage, and resulting import and export of electricity from/to the grid – see HEM-TP-18 PV generation and self-consumption.

Results are then returned to the wrapper (if any) for post-processing, and also written to the relevant output files.

## 2.1. Water heating calculation structure

(Step 1 from the description of “Overall calculation structure”)

The general structure of the water heating calculation is described in HEM-TP-09 Energy for domestic hot water. At a high level, it consists of two stages:

1. Calculate demand for hot water.
2. Calculate energy required by water heating system to provide the hot water required.

## 2.2. Space heating and cooling calculation structure

(Step 2 from the description of “Overall calculation structure”)

The general structure of the space heating calculation is as follows:

1. The internal and solar gains for each zone are calculated (internal gains from hot water are inputs to the space heating calculation and are added to the total internal gains)
2. The Project object retrieves from the heating/cooling system object assigned to each zone:
    a. Convective fraction
    b. Heating/cooling setpoint (the heating/cooling system object in turn retrieves this from the control object assigned to the heating/cooling system).
3. The Project object provides these setpoints and convective fractions to the appropriate Zone objects.
4. The Zone objects calculate space heating/cooling demand for the zone they represent (retrieving other inputs from various other objects representing building elements, ventilation elements etc.) and return the results to the Project object.

5. The Project object feeds these space heating/cooling demand values to the relevant space heating/cooling system object(s).
6. The space heating/cooling system object(s) then calculate:
    a. The energy supplied by the system (which does not necessarily meet the demand or could exceed the demand if controls are poor), which is then returned to the Project object.
    b. The associated fuel consumption, which is provided to the relevant EnergySupply object(s) to which they are connected.
7. The Project object then feeds the energy supplied by heating/cooling systems into the relevant Zone objects, where resulting temperatures achieved are calculated and saved (as internal state) for the next timestep.

Within step 6 above, the heating/cooling system can be represented by one or more objects with or without internal state. For example, an instantaneous electric heater is represented by a single object with no internal state whereas a central heating system will be represented by separate objects for the emitter system and the heat source (e.g., boiler or heat pump) which do have internal state (e.g., temperature of emitters).

## 2.3. Systems providing several services

(Step 3 from the description of “Overall calculation structure”)

For systems that provide several services (e.g., combi boiler providing hot water and space heating) there may be some dependency between the services. For example, the combined power output provided for each service cannot exceed the maximum power output of the system. Therefore, these modules contain additional internal state variables to track these dependencies. These internal state variables need to be reset at the end of the timestep, and it is also at this time that any other calculations requiring results from all the service calculations are performed.

As an example, for a heat pump providing both water heating and space heating, calculations within the heat pump object would be as follows (simplified description):

1. Water heating demand would be provided as input (part of step 1 from the description of “Overall calculation structure”), and the performance of the heat pump would be calculated, including the required running time to satisfy the demand for water heating. This running time would then be stored in an internal state variable in the heat pump object.
2. Space heating demand would be provided as input (step 6 from the description of “Space heating calculation structure”), and the performance of the heat pump would be calculated, including the required running time to satisfy the demand for space heating, and taking into account the running time already required for water heating. The internal

state variable tracking running time in the heat pump object would then be updated with the combined running time.

3. After all services have been calculated (step 4 from the description of “Overall calculation structure”), the combined running time is used to calculate additional energy consumption due to cycling behaviour.

# Future development

The model is currently limited to one heating system per zone and one cooling system per zone, but future development effort could be put into allowing the model to handle more than one heating/cooling system per zone. See HEM-TP-04 Space heating and cooling demand for how space heating and cooling demand might be calculated for more than one system.

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This publication is available from: https://www.gov.uk/government/publications/home-energy-model-technical-documentation